FORM PTO-1390 (REV 11-98)	U.S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER 124-838
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U.S APPLICATION NO. (If known, see 37 C.F.R. 1.5) 09/762805 Unknown
INTERNATIONAL APPLICATION NO. PCT/GB99/03055	INTERNATIONAL FILING DATE 14 September 1999	PRIORITY DATE CLAIMED 14 September 1998

TITLE OF INVENTION

FABRICATION OF OPTICAL WAVEGUIDES

APPLICANT(S) FOR DO/EO/US

SMITH et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.

2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.

3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).

4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.

5. A copy of the International Application as filed (35 U.S.C. 371(c)(2)).

   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).

6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).

7. ☒ Amendments to the claims of the International Application under PCT Article 34.

   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has **NOT** expired.
   d. ☐ have not been made and will not be made.

8. ☐ A translation of the amendments to the claims under PCT Article 19 (U.S.C. 371(c)(3)).

9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).

10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. To 16. Below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98.

12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included.

13. ☒ A FIRST preliminary amendment.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.

14. ☐ A substitute specification.

15. ☐ A change of power of attorney and/or address letter.

16. ☒ Other items or information. **PTO-1449/ International Search Report**

☐ This application is entitled to "Small entity" status. ☐ "Small entity" statement attached.

JC02 Rec'd PCT/PTO 13 FEB 2001

U.S. APPLICATION NO (If known, see 37 C.F.R. 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
09/762805 Unknown	PCT/GB99/03055	124-838

17. ☒ The following fees are submitted:

	CALCULATIONS PTO USE ONLY
BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5):	
-- Neither international preliminary examination fee (37 C.F.R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1000.00	
-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO $860.00	
-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but international search fee (37 C.F.R. 1.445(a)(2) paid to USPTO $710.00	
-- International preliminary examination fee paid to USPTO (37 C.F.R. 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) $690.00	
-- International preliminary examination fee paid to USPTO (37 C.F.R. 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) $100.00	
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 860.00
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(e)).	$ 0.00

CLAIMS	NUMBER FILED		NUMBER EXTRA	RATE			
Total Claims	12	-20 =	0	X	$18.00	$	0.00
Independent Claims	2	-3 =	0	X	$80.00		0.00
MULTIPLE DEPENDENT CLAIMS(S) (if applicable)					$270.00	$	0.00

TOTAL OF ABOVE CALCULATIONS =	$	**860.00**
Reduction by ½ for filing by small entity, if applicable. Small entity status must also be asserted. (Note 37 C.F.R. 1.9, 1.27, 1.28).		0.00
SUBTOTAL =	$	**860.00**
Processing fee of $130.00, for furnishing the English Translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(f)). +		0.00
TOTAL NATIONAL FEE =	$	**860.00**
Fee for recording the enclosed assignment (37 C.F.R. 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 C.F.R. 3.28, 3.31). **$40.00** per property +	$	40.00
Fee for Petition to Revive Unintentionally Abandoned Application ($1240.00 – Small Entity = $620.00)	$	0.00
TOTAL FEES ENCLOSED =	$	**900.00**
Amount to be: refunded	$	
Charged	$	

a. ☒ A check in the amount of $900.00 to cover the above fees is enclosed.
b. ☐ Please charge my Deposit Account No. 14-1140 in the amount of $_____ to cover the above fees. A duplicate copy of this form is enclosed.
c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 14-1140. A duplicate copy of this form is enclosed.
d. ☐ The entire content of the foreign application(s), referred to in this application is/are hereby incorporated by reference in this application.

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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27,393 REGISTRATION NUMBER

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of

SMITH et al.

Atty. Ref.: 124-838

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Group:

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Examiner:

For: FABRICATION OF OPTICAL WAVEGUIDES

February 13, 2001

Assistant Commissioner for Patents
Washington, DC 20231
Sir:

PRELIMINARY AMENDMENT

In order to place the above-identified application in better condition for examination, please amend the application as follows:

IN THE CLAIMS

Claim 4, line 1, delete "or claim 3".

Claim 6, line 1, change "any one of claims 1 to 4" to --claim 1--.

Claim 7, line 1, change "any one of claims 1 to 6" to --claim 1--.

Claim 8, line 1, change "any one of claims 1 to 6" to --claim 1--.

Claim 9, line 2, change "any one of the preceding claims" to --claim 1--.

REMARKS

The above amendments are made to place the claims in a more traditional format.

Respectfully submitted,

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FABRICATION OF OPTICAL WAVEGUIDES

This invention relates to the fabrication of optical waveguides.

One known technique for fabricating optical waveguides is the so-called direct bonding (or direct interfacial bonding) technique.

Direct bonding (DB) is a fabrication technique that uses the Van der Waals forces present when two atomically flat bodies approach each other to create a bond between two bodies. If the bodies are laminas of optical material having appropriate refractive indices, the material laminas can be joined to form waveguiding boundaries.

In one established way to form such a bond the surfaces of two pieces of optical material are polished so as to be very flat (i.e. substantially flat at atomic dimensions). The crystalline structures of the two polished faces are preferably aligned with each other and the polished faces are pressed together. A heat treatment can be useful to encourage a pyroelectric effect and the exchange of electrons between the two surfaces. This gives rise to an electrostatic attraction between the two surfaces, which tends to expel any remaining air or liquid from between the two surfaces. A final annealing step can improve the bond strength further.

A DB bond can be formed irrespective of the lattice constants and orientation of the bodies involved and causes no degradation on the crystalline microstructure or either material. By contacting surfaces in such a non-destructive way, DB preserves the bulk characteristics of each bonded material whilst avoiding possible problems caused by lattice defects, such as increased propagation loss and optical damage.

EP-0598395 describes forming an optical waveguide device by direct bonding of a support substrate and a low refractive index layer on a glass substrate, then etching the glass substrate.

This invention provides an optical waveguide comprising at least a guiding lamina of optical material bonded by direct interfacial bonding to a superstructure lamina of optical material, in which regions of the guiding lamina have modified optical properties so as to define a light guiding path along the guiding lamina characterised in that the waveguide further comprises a second superstructure lamina bonded by direct interfacial bonding to the guiding lamina.

The invention recognises and addresses the shortcomings of previous proposals for the use of DB structures in optical waveguides. In such previous proposals, a flat lamina of a material having a raised refractive index (forming a waveguide "core") is

bonded between two laminas of material having a lower refractive index (forming a waveguide "superstructure"). While this provided a bulk guiding structure, the large

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lateral dimension of the flat "core" lamina meant that the arrangement was not useful for many waveguiding applications or as a single-mode waveguide.

In contrast, in the invention, regions of the core lamina have modified optical properties so as to define a light guiding path along the core lamina. This can give a greatly increased flexibility of use and allow the guiding path to be much more tightly defined than in previous arrangements.

Although the method is suitable for use with many types of materials, such as glasses, it is preferred that the core lamina is a ferroelectric material, allowing the modified regions to be generated by electrical poling.

A particularly useful ferroelectric material having well-studied optical and electrical properties, is periodically poled lithium niobate (PPLN). PPLN combines a large non-linear coefficient, a widely-controllable phase-matching wavelength, and zero walk-off characteristics that make it an ideal material to achieve quasi-phase matching (QPM) for non-linear frequency conversion. With recent improvements in the efficiency of second-harmonic generation (SHG) within PPLN substrates, it is recognised in the present invention that the use of such a material in an appropriate waveguide geometry formed using the invention can provide a realisation of various compact non-linear devices based on harmonic or parametric generation.

The present method is particularly appropriate for use with PPLN, and has several advantages over other techniques for fabricating waveguides using PPLN such as the so-called "annealed proton exchange" technique and the "titanium indiffusion" technique, both of which act on a single PPLN crystal and modify the crystal near the surface in order to create regions of higher refractive index for optical confinement.

Previous experiments investigating the bonding characteristics of PPLN have been directed towards fabricating thick multi-laminated stacks of the material for a large physical aperture, and thus high power applications. In contrast, creating a sufficiently thin lamina of PPLN increases the average pump intensity applied to the domain-inverted structure via optical confinement, and thus allows efficient SHG even at low pump powers. Fabrication of such a device is obtainable by bonding PPLN onto a suitable substrate before precision polishing down to waveguide dimensions, a

method which has already been demonstrated in the production of $LiNbO_3$ planar waveguides for electro-optic applications. One of the primary attractions offered by this technique is that the non-linearity and domain characteristics of the PPLN structure after bonding should remain unchanged from the bulk material – a combination that annealed proton exchange and Ti indiffusion methods are close to achieving, but not yet at their full theoretical efficiencies. A further advantage of the present method is the extra flexibility available when designing devices, as combinations of multiple laminas with different material properties are now possible.

Viewed from a second aspect this invention provides a method of fabricating an optical waveguide, the method comprising the steps of:

(a) bonding, by direct interfacial bonding, a guiding lamina of optical material to a superstructure lamina of optical material;

(b) before, during or after step (a), modifying optical properties of regions of the guiding lamina so as to define a light guiding path along the guiding lamina;

characterised in that the method further comprises the steps of:

(c) after steps (a) and (b), removing material from the guiding lamina to reduce the thickness of the guiding lamina (10) ; and

(d) after step (c), bonding, by direct interfacial bonding, a further superstructure lamina (20) to the guiding lamina.

Embodiments of the inventions will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of a waveguide formed using a lamina of PPLN bonded between two laminas of lithium tantalate;

Figure 2 schematically illustrates a second harmonic generator using the waveguide of Figure 1;

Figure 3 is a graph relating the square root of second harmonic power to launch power for the apparatus of Figure 2;

Figures 4 and 5 are schematic diagrams illustrating the fabrication of a waveguide according to an embodiment of the invention using an indiffusion technique; and

Figure 6 schematically illustrates a waveguide according to a further embodiment of the invention.

In the following description, preparation and use of an example waveguide as a second harmonic generator will first be described with reference to Figures 1 to 3. Then, other waveguides also forming embodiments of the invention will be described.

Figure 1 schematically illustrates a waveguide formed as a directly bonded sandwich of a lamina 10 of PPLN between two laminas 20 of lithium tantalate ($LiTaO_3$).

The PPLN lamina 10 is in the form of a PPLN grating, in that the lithium niobate ($LiNbO_3$) material is poled in a periodic, "striped" arrangement. These "stripes" of alternately poled regions in the lithium niobate material are shown schematically in Figure 1 as alternate black and white stripes, although it will be appreciated that in reality the periodic poling structure would almost certainly not be detectable by the human eye.

Production of the PPLN grating began with a 0.5-mm-thick single domain z-cut $LiNbO_3$ sample of about 15 mm x 15 mm surface area. A photoresist pattern was created on the z-face of the crystal by photolithography. This formed regions on the crystal surface which are covered by an electrical insulator, and regions which are not so covered. A liquid electrode was then applied to the partially insulated surface, and domain inversion in the z-axis was performed at room temperature by the application of a single high voltage pulse of ~ 11 kV through the liquid electrode. This resulted in three 5.5-mm-long PPLN gratings, positioned in the centre of the $LiNbO_3$ sample at 1 mm intervals. Grating periods of 6.58, 6.50, and 6.38 μm were created, the first two of which are suitable for frequency doubling of a Nd:YAG laser operating at 1064 nm.

$LiTaO_3$ was chosen as a suitable material for both the substrate and superstructure laminas as it combines thermal characteristics that are a good match for $LiNbO_3$, an important pre-requisite when annealing bonds at high temperatures, together with a refractive index lower than that of $LiNbO_3$.

Each $LiTaO_3$ substrate was 0.5-mm-thick and shaped relative to the PPLN sample to provide a bonding area of about 12mm x 10 mm between the two optically flat surfaces. To form a bond between an $LiTaO_3$ substrate and the PPLN grating, the two materials were first cleaned, then a mixture of H_2O_2-NH_4OH-H_2O (1:1:6) was applied to both materials, followed by several minutes of rinsing in de-ionised water, in order to render their surfaces hydrophilic.

Contacting of the PPLN and $LiTaO_3$ laminas was performed at room temperature with both samples aligned along the same crystalline orientation. A heat treatment of 120°C immediately followed crystal contact to induce the pyroelectric effect at the DB interface. The resultant electrostatic attraction forced any excess air or liquid from between the two surfaces, whilst bringing them close enough to encourage the formation of hydrogen bonds. This effect was evident by the elimination of most contact fringes at the crystal interface. Annealing of the bonded sample at 320°C for 6 hours provided a bond strength sufficient for further machining, and the PPLN region was lapped down to obtain a waveguiding lamina of 12-μm-thickness.

The second superstructure lamina of $LiTaO_3$ was then added as above. The final DB structure included bonded interfaces of about 12mm x 10 mm above and below the PPLN core, although evidence of small unbonded regions at the edges of the sample were detected by the presence of optical fringes. The unnecessary material surrounding the gratings was later removed using dicing equipment and the waveguide end-faces were then polished to a parallel optical finish. Dimensions of the resulting buried PPLN planar structure are given schematically in Figure 1.

An upper limit for the value of the propagation loss of the waveguide structure was found by measuring the transmission of a 1064 nm laser beam when end-launched into the waveguide. It was noted that the transmission changed between the PPLN and unpoled $LiNbO_3$ sections, although this was not due to SHG. The launch from a microscope objective was empirically optimised for each region and maximum transmissions of 81% were found at the edges of the poled regions (where the best SHG occurred) and throughout the unpoled $LiNbO_3$ sections, whilst 65% transmission was obtained at the centre of the PPLN region. Thus, taking into account the 5.5-mm-length of the grating, an upper-limit to the propagation loss in each section can be placed as 1.7 dB cm^{-1} for the PPLN edges and unpoled $LiNbO_3$ regions, and 3.4 dB cm^{-1} for the central PPLN region. In reality, these transmission figures also include a certain loss due to non-perfect launching and so the propagation losses are likely to be much lower. Indeed, DB waveguides in garnets and glasses for laser applications have shown losses of ~0.5 dB cm^{-1} and less.

To test the non-linear properties of the buried PPLN structure. the SHG characteristics of the 6.50 μm grating were investigated. This grating, which occupied the middle section of the PPLN waveguide, successfully suppressed the photorefractive effect at its phase-matching temperature of 174.1°C and so was chosen for further analysis. The 1064 nm pump source was a cw diode-pumped Nd:YAG laser 30 operating with multi-axial modes. The linear polarisation state was rotated with a half-wave plate (not illustrated) to be parallel with the z-axis of the PPLN in order to access the material's largest non-linear coefficient (d_{33}). Focusing of the pump radiation for launching into the waveguide was performed using a combination of microscope objectives and cylindrical lenses, as shown in Figure 2. In particular, the initially circular pump beam was passed through a spherical collimating lens 40 and into a x2.4 cylindrical-lens telescope 50 to produce widening in the non-guided direction before being focused onto a poled region of the PPLN waveguide device 70 of Figure 1 by a x10 microscope objective 60. Such a combination of optics was chosen to provide good launch efficiency whilst helping to reduce divergence in the horizontal unguided plane. This resulted in a pump source with a line focus and measured spot sizes of 4±1 μm in the guided direction and 11±1 μm in the non-guided direction.

It should be noted that focusing to a waist in the non-guided plane at the input face is not necessarily the optimum condition for maximum SHG efficiency. However, it was used in this demonstration due to the simplicity of having one x10 objective as the focusing element instead of a more complicated cylindrical-lens launching arrangement. Also, for this initial demonstration, both the input and output end-faces of the waveguide were polished but left uncoated, leading to 14% reflection losses at each face.

The waveguide device 70 was placed in an oven 80 to maintain the waveguide's temperature at the phase-matching temperature of 174.1°C.

A second x10 microscope objective 90 was used to collect the transmitted light from the waveguide. This was followed by an infra-red filter 100 to block any throughput from the pump beams, allowing the generated green output of the PPLN to

be measured by an optical power meter. For 204 mW of launched pump power (λ = 1064 nm), a second-harmonic (SH) power of 1.8 mW (λ = 532 nm) was generated internal to the crystal. Figure 3 shows a plot of the square root of the SH power versus launched pump power, revealing a quadratic dependence between the measured values.

It should of course be noted that the system of Figure 2 is a specific example of an optical parametric device. The waveguide would be suitable for use in many other such devices.

Due to the unusual pumping geometry used while testing the PPLN waveguide, any calculation of the SHG efficiency from the device would be complicated. Instead, the most interesting comparison to make is with a calculation of the SH power expected from a similar length of bulk PPLN with optimised focusing in the centre of the grating. Assuming a non-linear coefficient of 16 pm V^{-1} (a value consistent with results in bulk experiments using similarly produced PPLN gratings), it is possible to produce a SH output power of 1.3 mW in the bulk material - a lower result than the 1.8 mW obtained from the direct-bonded waveguide. Therefore, it would appear that even with non-optimum focusing and only one guided dimension, the buried PPLN device shows an improved SHG efficiency over the bulk material.

Characterisation of the output modes of the PPLN waveguide was performed by the use of a video camera and PC-based evaluation software. Surprisingly, it was observed that both the 1064 nm throughput and the SH generated 532 nm radiation from the PPLN waveguide were in the fundamental spatial mode, an unexpected result for a 12-μm-thick guide with such a large index difference ($\Delta n_e \approx 1\%$). Indeed, only by using a deliberately poor launch was it possible to excite anything other than the fundamental mode at 1064 nm. Even more unusual was the result that the 1064 nm throughput from the unpoled $LiNbO_3$ region within the same buried structure was multi-spatial-mode in nature. This clear difference in the mode properties, combined with the apparently different transmissions described earlier, suggests that the index profile of the PPLN section is different to that of the unpoled $LiNbO_3$ section.

In summary, for the first embodiment of the invention these experiments demonstrate the successful prototype fabrication of a 12-μm-thick, 5.5-mm-long,

symmetrical PPLN waveguide buried in $LiNbO_3$ by DB. Using the 6.50-μm-period PPLN grating at an elevated temperature of 174°C, an efficient quasi-phase-matched frequency doubling of the 1064 nm line of a cw diode-pumped Nd:YAG laser has been demonstrated. For 204 mW of fundamental pump power, nearly 2 mW of green power was generated at an output wavelength of 532 nm. This result was obtained with non-optimum focusing conditions but remains higher than the theoretical expectation for a similar length of bulk material. The waveguiding properties were shown to be different in the PPLN and unpoled $LiNbO_3$ regions of the sample, with the PPLN section showing a surprising single-spatial-mode behaviour. These results suggest that the production of longer buried waveguides, potentially incorporating channel structures, should lead to highly-efficient non-linear devices. With a full characterisation of propagation losses and effects of strain upon the index profile, the DB technique should allow extra freedom, and hence new device possibilities, in the choice of non-linear waveguiding structures.

The techniques described above are not limited to PPLN, but can be applied to any optically useful poled ferroelectric material such as $LiTaO_3$, doped $LiNbO_3$ (e.g. Mg-, Ti- or rare earth doped), strontium barium niobate, barium titanate, potassium titanyl phosphate and its isomorphs, polar semiconductors such as gallium arsenide and so on.

The poling of the PPLN can be carried out before, during, between and/or after the bonding stages. If the poling is carried out other than before the bonding stages and a ferroelectric material is used for the other laminas, then those other laminas can also end up being poled. This may change the guiding properties of the waveguide but does not prevent operation as a waveguide. Indeed, the bonding properties may even be improved by this measure (or by poling the other laminas separately).

In the example above, a poled area is used to define a waveguiding path along the lamina 10, but with other substrates it may be found that an unpoled lamina offers a more appropriate path.

It is not necessary to surround the lamina 10 by two other laminas 20. Instead, one lamina 20 could be used, to form an "open sandwich" structure of just two

laminas. In this case the symmetry of the structure would be altered and the guided mode(s) would probably be different, but operation as a waveguide would still be possible.

The thickness of the lamina 10 can be altered, again altering the nature of the guided mode(s) in the waveguide. In this way, a single mode structure can be fabricated.

Referring now to Figures 4 and 5, a second embodiment using an indiffusion technique to define a waveguide path will be described.

In this second embodiment, a piece of PPLN 100 is made by the conventional electrical poling method. The piece 100 might be, for example, 500μm thick and several mm in the other two dimensions. One face 110 of the piece 100 is patterned with magnesium oxide (using a process of photolithography and vacuum evaporation or sputtering). The magnesium oxide lamina is less than about 400nm thick, and defines (by the parts not covered by the lamina) a waveguide path along the piece 100. The piece 100 is then heated to a temperature of between about 600°C and about 1200°C. This causes the magnesium oxide material to diffuse in and, in the indiffused regions 130, locally lower the refractive index.

The piece 100 is then bonded, by a direct bonding process applied to the face 110, to a $LiTaO_3$ substrate (140, Figure 5), before being polished down to a substantially uniform thickness of between, say, about 4μm and about 40μm.

A further magnesium oxide pattern is then deposited on the exposed (newly polished) face of the piece 100, and the heat treatment repeated. This causes the magnesium oxide to indiffuse from the other side, to match the indiffusion from the face 110. Regions 150 of reduced refractive index are thus formed, defining a waveguiding core 160.

This technique, or a complementary out-diffusion technique, is applicable not only to other ferroelectric materials (for examples, see above), but also to any substrates whose refractive index can be altered by an indiffusion technique, such as various glasses, polymers and other crystals. The common advantage shared between

all applications of this technique is that the guiding region 160 can be formed of unadulterated material.

Similarly, in all of the embodiments, the "superstructure" laminas can be of various materials such as unpoled $LiNbO_3$ or other suitable materials from the lists above.

It is possible to fabricate curved waveguide paths using the above techniques. In the case of the first embodiment, a poling pattern similar to that shown schematically in Figure 6 can be used, where a series of poled regions form a track 170 which bifurcates as a signal splitter. In the case of $LiNbO_3$ there is a preferred poling direction resulting form the crystal structure, but the arrangement of Figure 6 gets around this restriction to form curved or varying-direction paths using multiple displaced poled stripes.

PUBLICATION REFERENCES

[1] J A Armstrong, N Bloembergen, J Ducuing, and P S Pershan, Phys. Rev. 125. 1918 (1962)

[2] G W Ross, M Pollnau, P G R Smith, W A Clarkson, P Britton, and D C Hanna, Opt. Lett. 23. 171 (1998)

[3] K Kintaka, M Fujimura, T Suhara, and H Nishihara, J. Lightwave Tech. 14. 462 (1996)

[4] M A Arbore and M M Fejer, Opt. Lett. 22. 151 (1997)

[5] P Baldi, M P De Micheli, K E Hadi, S Nouh, A C Cino, P Aschieri, and D B Ostrowsky, Opt. Eng. 37. 1193 (1998)

[6] J Amin, V Pruneri, J Webjorn, P St J Russell, D C Hanna, and J S Wilkinson, Opt. Comm. 135. 41 (1997)

[7] J Haisma, B A C M Spierings, U K P Biermann, and A A van Gorkum, Appl. Opt. 33. 1154 (1994)

[8] K Eda, M Sugimoto, and Y Tomita, Appl. Phys. Lett. 66. 827 (1994)

[9] M J Missey, V Dominic, L E Myers, and R C Eckardt, Opt. Lett. 23. 664 (1998)

[10] Y Tomita, M Sugimoto, and K Eda, Appl. Phys. Lett. 66. 1484 (1995)

[11] J Haisma, T M Michielsen, and F J H M van der Kruis, Phillips J. Res. 49. 65 (1995)

[12] C T A Brown, C L Bonner, T J Warburton, D P Shepherd, A C Tropper, D C Hanna, and H E Meissner, Appl. Phys. Lett. 71. 1139 (1997)

[13] G A C M Spierings, J Haisma, and T M Michielsen, Phillips J. Res. 49. 47 (1995)

[14] G D Boyd and D G Kleinmann, J. Appl. Phys. 39. 3597 (1968)

CLAIMS

1. An optical waveguide comprising at least a guiding lamina (10) of optical material bonded by direct interfacial bonding to a superstructure lamina (20) of optical material, in which regions of the guiding lamina have modified optical properties so as to define a light guiding path along the guiding lamina (10), characterised in that the waveguide further comprises a second superstructure lamina (20) bonded by direct interfacial bonding to the guiding lamina.

2. A waveguide according to claim 1, in which the guiding lamina (10) is formed of a ferroelectric material.

3. A waveguide according to claim 2, in which the guiding lamina is formed of lithium niobate.

4. A waveguide according to claim 2 or claim 3, in which the modified regions are electrically poled regions of the guiding lamina.

5. A waveguide according to claim 4, in which the modified regions are spatially periodical electrically poled regions of the guiding lamina.

6. A waveguide according to any one of claims 1 to 4, in which the modified regions (130, 150) are formed by indiffusion of one or more dopant materials into the guiding lamina.

7. A waveguide according to any one of claims 1 to 6, in which at least part of the modified regions form the light-guiding path.

8. A waveguide according to any one of claims 1 to 6, in which the light guiding path (160) is formed of an unmodified region of the guiding lamina, the modified regions defining boundaries of the light guiding path.

9. An optical parametric device comprising:

a waveguide according to any one of the preceding claims; and

means for launching an input optical signal into the waveguide.

10. A device according to claim 9, comprising:

an output filter for filtering light emerging from the waveguide to reduce components at the wavelength of the input optical signal.

11. A method of fabricating an optical waveguide, the method comprising the steps of:

(a) bonding, by direct interfacial bonding, a guiding lamina (10) of optical material to a superstructure lamina (20) of optical material; and

(b) modifying optical properties of regions (130, 150) of the guiding lamina so as to define a light guiding path along the guiding lamina, characterised in that the method further comprises the steps of:

(c) after steps (a) and (b), removing material from the guiding lamina to reduce the thickness of the guiding lamina (10) ; and

(d) after step (c), bonding, by direct interfacial bonding, a further superstructure lamina (20) to the guiding lamina.

12. A method according to claim 11, further comprising:

(e) before step (a), indiffusing and/or out-diffusing material to/from one face of the guiding lamina to modify regions of the guiding lamina, that face being bonded to the superstructure lamina in step (a); and

(f) before step (d), indiffusing and/or out-diffusing material to/from the exposed face of the guiding lamina to modify regions of the guiding lamina, that face being bonded to the further superstructure lamina in step (d).

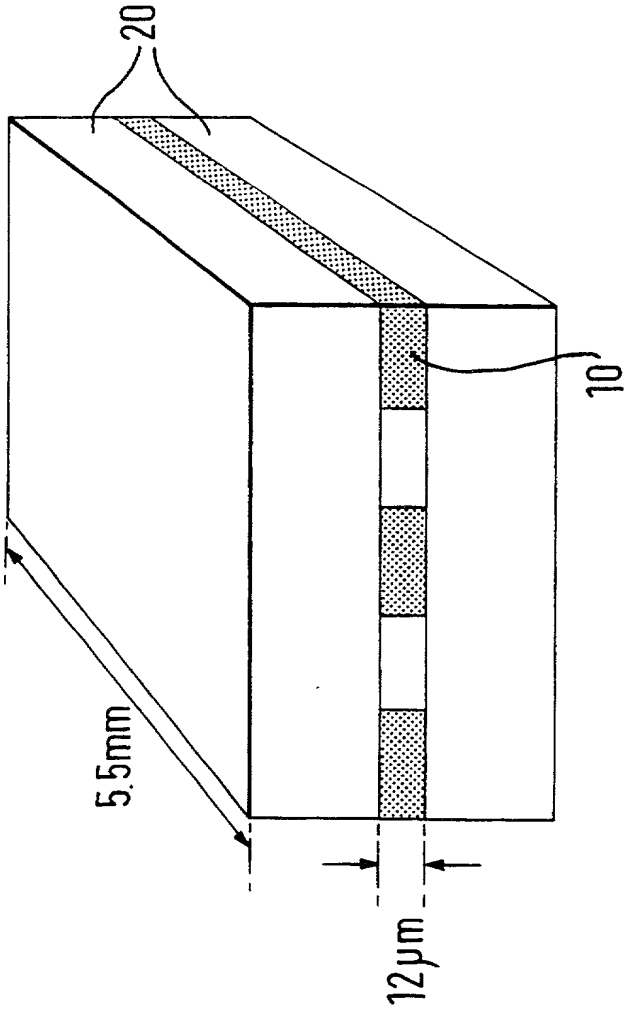
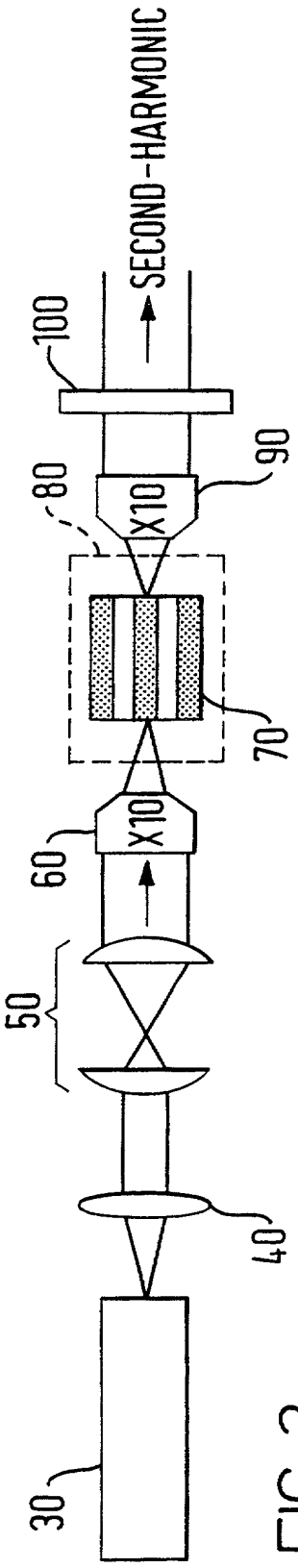


FIG.1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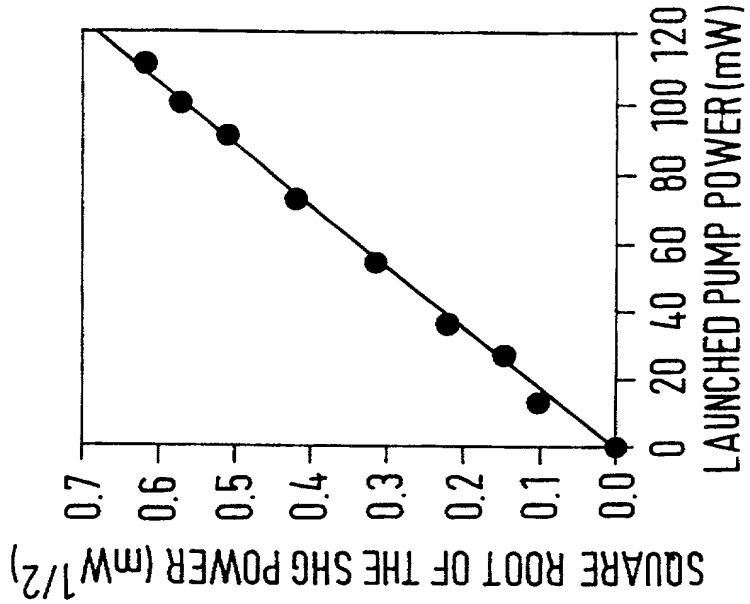
100
80
X10
90
70
60
X10
50
40
30

FIG. 2

FIG. 3


SQUARE ROOT OF THE SHG POWER (mW 1/2)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 20 40 60 80 100 120
LAUNCHED PUMP POWER(mW)

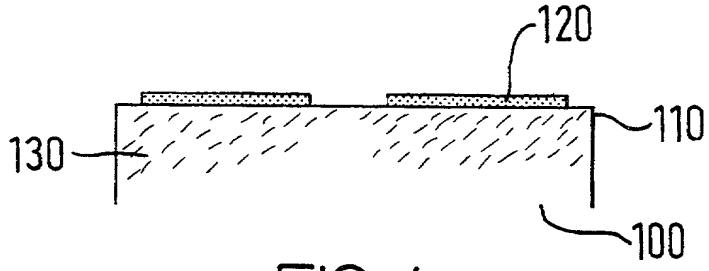


FIG. 4

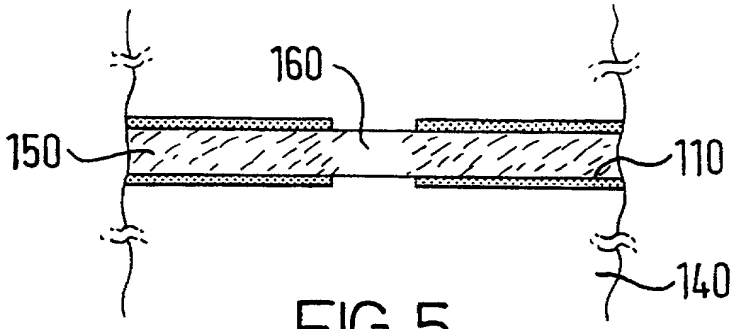


FIG. 5

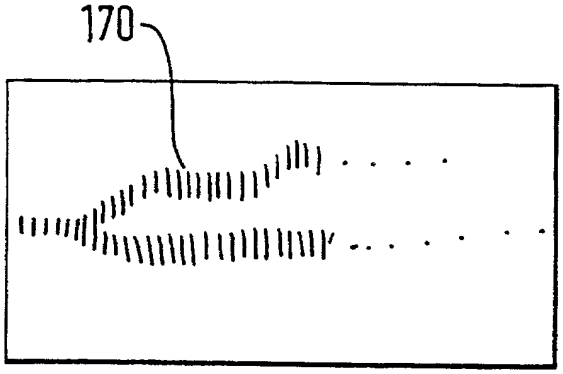


FIG. 6

RULE 63 (37 C.F.R. 1.63)
DECLARATION AND POWER OF ATTORNEY
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the specification of which (**check** applicable **box(s)**):

☐ is attached hereto

☐ was filed on _____ as U.S. Application Serial No. _____ Atty Dkt. No. P3139/USW

☒ was filed as PCT International application No. PCT/GB99/03055 on 14/09/1999

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PCT/GB99/0355	14/09/1999	PENDING

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1. Inventor's Signature: Peter G SMITH Date: 18/4/00

Inventor: Peter (first) G R MI SMITH (last) GB (citizenship)

Residence: (city) ROMSEY, HAMPSHIRE (state/country) GB GB3

Post Office Address: 38 EIGHT ACRES, ROMSEY, Great Britain

(Zip Code) SO51 5BQ

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Inventor: Graeme (first) W MI ROSS (last) GB (citizenship)

Residence: (city) ABERDEEN (state/country) GB GB3

Post Office Address: 35 Gladstone Place, Queen's Cross, Aberdeen, Great Britain

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FOR ADDITIONAL INVENTORS, check box ☒ and attach sheet with same information and signature and date for each.

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3. Inventor's Signature: _____ Date: _____
Inventor: David (first) C MI HANNA (last) GB (citizenship)
Residence: (city) Southampton, Hampshire (state/country) GB GB3
Post Office Address: 346 Hill Lane, Shirley, Southampton, Hampshire, Great Britain
(Zip Code) SO15 7PH

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Inventor: Corin (first) B E MI GAWITH (last) GB (citizenship)
Residence: (city) Romford, ESSEX (state/country) GB GB3
Post Office Address: 24 Upland Court Road Harold Wood Romford Essex
(Zip Code) RM3 0TT

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1. Inventor's Signature: _____ Date: _____

Inventor: Peter (first) G R MI SMITH (last) GB (citizenship)

Residence: (city) ROMSEY, HAMPSHIRE (state/country) GB

Post Office Address: 38 EIGHT ACRES, ROMSEY, Great Britain

(Zip Code) SO51 5BQ

2. Inventor's Signature: Graeme W. Ross Date: 1 MAY 2000

Inventor: Graeme (first) W MI ROSS (last) GB (citizenship)

Residence: (city) ABERDEEN (state/country) GB

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(Zip Code) _____

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Inventor: Graeme (first) W MI ROSS (last) GB (citizenship)

Residence: (city) ABERDEEN (state/country) GB

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FOR ADDITIONAL INVENTORS, check box ☒ and attach sheet with same information and signature and date for each.

RULE 63 (37 C.F.R. 1.63)
DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Nixon & Vanderhye P.C. (12/95)

3. Inventor's Signature: _____ Date: _____
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6. Inventor's Signature: _____ Date: _____
Inventor: (first) MI (last) (citizenship)
Residence: (city) (state/country)
Post Office Address:
(Zip Code)

7. Inventor's Signature: _____ Date: _____
Inventor: (first) MI (last) (citizenship)
Residence: (city) (state/country)
Post Office Address:
(Zip Code)

8. Inventor's Signature: _____ Date: _____
Inventor: (first) MI (last) (citizenship)
Residence: (city) (state/country)
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9. Inventor's Signature: _____ Date: _____
Inventor: (first) MI (last) (citizenship)
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10. Inventor's Signature: _____ Date: _____
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RULE 63 (37 C.F.R. 1.63)
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As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name, and I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

the specification of which (**check** applicable **box(s)**):

☐ is attached hereto

☐ was filed on _____ as U.S. Application Serial No. _____ Atty Dkt. No. P3139/USW

☒ was filed as PCT international application No. PCT/GB99/03055 on 14/09/1999

and (if applicable to U.S. or PCT application) was amended on _____

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with 37 C.F.R. 1.56. I hereby claim foreign priority benefits under 35 U.S.C. 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed or, if no priority is claimed, before the filing date of this application:

Priority Foreign Application(s):

Application Number	**Country**	**Day/Month/Year Filed**
9820024.9	GB	14/09/1998

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below.

Application Number	**Date/Month/Year Filed**

I hereby claim the benefit under 35 U.S.C. 120/365 of all prior United States and PCT international applications listed above or below and, insofar as the subject matter of each of the claims of this application is not disclosed in such prior applications in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose material information as defined in 37 C.F.R. 1.56 which occurred between the filing date of the prior applications and the national or PCT international filing date of this application:

Prior U.S./PCT Application(s): Application Serial No.	**Day/Month/Year Filed**	**Status: patented pending, abandoned**
PCT/GB99/0355	14/09/1999	PENDING

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon. And I hereby appoint **NIXON & VANDERHYE P.C., 1100 North Glebe Rd., 8th Floor, Arlington, VA 22201-4714, telephone number (703) 816-4000 (to whom all communications are to be directed)**, and the following attorneys thereof (of the same address) individually and collectively my attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and with the resulting patent: Arthur R. Crawford, 25327; Larry S. Nixon, 25640; Robert A. Vanderhye, 27076; James T. Hosmer, 30184; Robert W. Faris, 31352; Richard G. Besha, 22770; Mark E. Nusbaum, 32348; Michael J. Keenan, 32106; Bryan H. Davidson, 30251; Stanley C. Spooner, 27393; Leonard C. Mitchard, 29009; Duane M. Byers, 33363; Jeffry H. Nelson, 30481; John R. Lastova, 33149; H. Warren Burnam, Jr. 29366; Thomas E. Byrne, 32205; Mary J. Wilson, 32955; J. Scott Davidson, 33489; Alan M. Kagen, 36178; William J. Griffin, 31260; Robert A. Molan, 29834; B. J. Sadoff, 36663; James D. Berquist, 34776; Updeep S. Gill, 37334; Michael J. Shea, 34725; Donald L. Jackson, 41090; Michelle N. Lester, 32331.*

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